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A paper presented at the 127th Meeting of the American Institute of Electrical Engineers, New York, September 28th, 1898, President Kennelly in the Chair.

THE PHOTOMETRY OF THE ENCLOSED ALTERNATING ARC.

BY CHARLES P. MATTHEWS, W. H. THOMPSON AND J. E. HILBISH.

INTRODUCTORY.

The enclosed arc of the direct current type has received a noteworthy development at the hands of Marks[1] and subsequent workers. It has been the subject of more or less experimental study by Houston and Kennelly, Freedman,[2] Hesketh,[3] Nichols[4] and a number of others on both sides of the Atlantic. The enclosed arc of the alternating current type is of somewhat more recent development and has received less attention experimentally. It was with the thought of observing something of the behavior of this latter type of illuminant that the data of the following pages were taken.

THE PHOTOMETRY OF THE ARC.

Arc light photometry, in so far as it involves the mere determination of luminous intensity[5] yields unsatisfactory results for three chief reasons: The first of these is the marked difference

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1. London *Electrician*, xxxviii, 615; March 5, 1897. See also "Proc. Electrical Congress," Chicago, 1893.

2. TRANSACTIONS, xiv, 361; August, 1897.

3. London *Electrician*, xxxviii, 798.

4. Sibley *Journal of Engineering*, xi, 368; June, 1897.

5. That our photometric nomenclature needs standardizing can not be doubted. The quantity that has been called *candle-power* is hardly appropriate if the Hefner unit be used. If we have arrived at the passing of the candle, should not *candle-power* go? This same quantity is variously styled *intensity*, *total intensity* (Palaz.,) *luminous intensity* and *brightness* (Nichols). The unit of *illumination* also goes by several names.

in quality between the light of the arc and that of any of the ordinary standards. The photometrist realizes the generally unsatisfactory character of the existing standards[6] for the study of sources of a quality similar to that of gas light. Nevertheless, he is vastly better off, in this respect, than he is in the matter of a standard of suitable quality and intensity for arc light measurement. The eye estimates accurately an equality of brightness in two surfaces only when those surfaces are of the same tint. Moreover, with a color difference, the judgment of an equality differs with different observers. It should be said, however, that the difficulty arising from difference of color is less troublesome in the case of the enclosed arc than in the case of its progenitor, the open arc. The inner, opalescent globe absorbs the rays of short wave-length in greatest proportion, a fact which brings the color of the arc nearer that of the standard. When an outer globe of milky glass is used—the standard being a glow lamp maintained at, or above, its normal voltage—there is no annoyance from color difference.

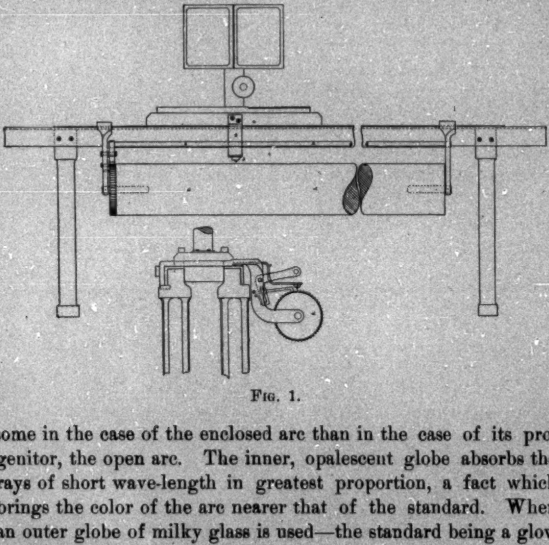

FIG. 1.

The second obstacle to careful measurement, is to be found in the variability of the quantity to be measured. These variations are largely due to the wandering condition of the arc—a peculiarity that is especially noticeable in the open alternating arc, and in both types of the enclosed arc. Indeed, it is to this feature of the enclosed arc that the flat-ended carbons are due. The change in luminous intensity corresponding to a shifting in the position of the arc from one side of the carbons to the other side is enormous. Curves of horizontal intensity showing the magnitude of these changes have already been published[7]. An attempt to get at the intensity of such a source by a few readings might easily lead to results discordant by 100 per cent. or more. The only hope of securing a result that will show the mean intensity of the arc is in taking a large number of settings, distributed, as to time, with some degree of uniformity. To accomplish this it would seem desirable to do away with the considerable and variable interval of time used, in the ordinary process, in reading the bar. This end was reached by the use of a mechanical device for recording a setting as soon as it is made. The essentials of this device will be readily understood from an inspection of Fig. 1. Its collateral advantages, for the study of personal error and for other photometric uses, have been dwelt upon in a note published elsewhere[8]. For our present purpose, it is sufficient to point out that it permits the observer to keep his eye continually trained on the photometer disk, so that all the major fluctuations may be readily followed and recorded, and this, too, without the visual fatigue resulting from introducing light into the photometer room. The act of depressing the rod *r* makes a permanent record on the paper surrounding the drum, and at the same time advances the drum so that the record may be subsequently identified.

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[6] See report of Nichols, Sharp and Matthews, TRANSACTIONS, xiii, p. 133, May, 1896.

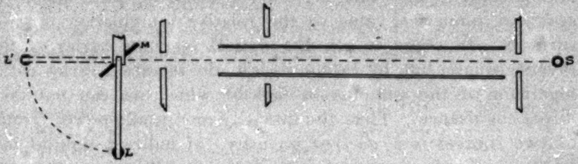

FIG. 2.

The inaccuracy of photometric settings, due to the causes just mentioned, is perhaps more a question of process than of principle. There is a third and more fundamental source of trouble—one, indeed, which brings into question the validity of the term "candle-power" as a measure of worth in illuminants. For the sake of clearness, let us first consider what the term means. A 16 C. P. lamp, for example, is one that produces at a distance of four units the same illumination that one candle produces at one unit. That is, if two similar surfaces be illuminated separately by these two sources at these distances, and if they be viewed in juxtaposition from the same direction, they appear equally bright. This is, in fact, what the photometer shows, and is really all that can be affirmed as a result of the comparison. Having established a distance ratio of 4 : 1, the observer applies the law of inverse square to calculate an intensity ratio of 16 : 1. This intensity ratio is *numerically* equal to the illumination ratio on two surfaces at unit distance, but it is important to note that an observer would be quite unable to assign a numerical value to the relative illumination of these surfaces. In other words, the optical stimulus varies as the inverse square, but, by Fechner's law, the sensation varies as the logarithm of the stimulus—a fact of which we can not take direct cognizance. Thus the intensity or "candle-power" ratio of two sources is a *derived* quantity, of indirect significance, whose chief value is to be found in the fact that it enables one to calculate an indefinite number of pairs of distances, at each of which will be found an *equality of illumination*. If two sources be compared by some method which takes account of their quality and which gives as a result the ratio of their total luminosities—determined, say by the relative value of their component rays in distinguishing characters—something quite different from their "candle-power" ratio may be obtained. These matters have already been brought to the attention of the members of the INSTITUTE by Nichols[9]. Fortunately the luminosity ratio of sources of nearly the same color, is not widely different from their intensity ratio. Hence it is to be hoped that, in the acetylene flame or some similar source, we shall soon have a suitable standard for the photometry of the arc.

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[7] Nichols, *loc. cit.*

[8] Matthews. Current number of the *Physical Review.*

ADJUSTMENT AND STANDARDIZATION OF APPARATUS.

For the photometric measurements, a Krüss-Bunsen photometer was used. The method adopted was the usual one of a swinging crane in connection with a 45° mirror. The total distance between sources was 829 cm. The coefficient of reflection of the mirror was determined by the use of two glow lamps connected in multiple. The lamp nearest the mirror was mounted at the end of an arm capable of being swung through an angle of 90°, as indicated in Fig. 2. This arrangement maintains the same length of bar with and without the mirror—a fact which makes for simplicity in the calculations. For the coefficient of reflection the first values obtained by three different observers were:

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[9] TRANSACTIONS, vi : 158, May, 1889.

H, .828 T, .826 M, .823

An inspection of the image of the arc in the mirror gave rise to the belief that the absorption of the luminous rays was in some degree selective—an undue proportion of the violet rays being taken up. Were this the case, the value of the coefficient determined by glow lamps would be incorrect for use with the arc itself. To test this matter, the electromotive force on the lamps was varied through a wide range and a determination made for each change. The values found were:

TABLE I.

Volts on Lamps.	Reflecting Power.
95	.824
105	.805
112	.785
117	.800
122	.782
127	.836
132	.808
137	.825

Although the change in the quality of the light was very marked in this experiment, the results do not indicate any regular change in the coefficient of reflection such as was looked for. Hence, in all subsequent measurements, the mean of these various determinations, namely .814, was used.

The standard source was a glow lamp; it was referred after each test to the Hefner lamp. Electrical measurements were made by various portable voltmeters, ammeters and wattmeters, all of which were repeatedly referred to Kelvin balances.

Results on the Alternating Arc.

A number of enclosed arc lamps, in their commercial form, were kindly placed at the disposal of the writers by their respective manufacturers. As this paper has no other object than to exhibit such features of the performance of these lamps as are largely typical, the trade names of the lamps are withheld.

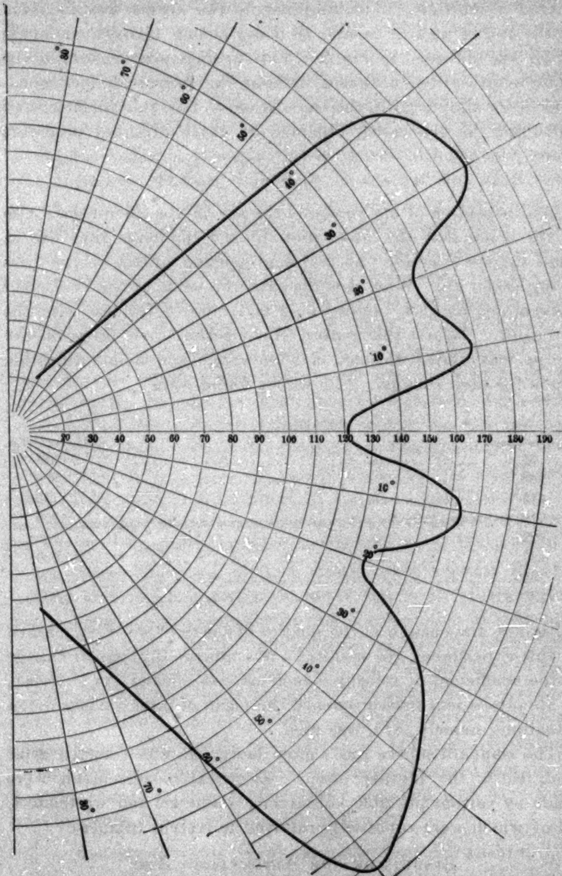

FIG. 3.—Distribution of Intensity. Lamp A.

For each position of the arc, no fewer than 44 photometric settings were recorded. It was found that this number was sufficient to include the maximum and minimum values, and a sufficient number of intermediate values to give a mean that could be reproduced quite closely at different times, thus showing the reliability of the method.

Lamp A.—The distribution of intensity from this lamp is shown in the polar diagram of Fig. 3; the figures for the curve are as follows:

TABLE II.

Angle.	Intensity.
0° horizontal	121.4 H. U.
10° above	169.0
20° "	155.0
30° "	189.0
40° "	176.0
50° "	46.5
60° "	22.4
10° below	164.5
20° "	134.7
30° "	167.4
40° "	187.5
50° "	203.0
60° "	180.5
70° "	82.6
80° "	64.0

The following is a summary of the results of the test of this lamp:

TABLE III.

Volts	103.2
Amperes	5.84
Apparent watts	602.
True watts	407.
Watts in mechanism	80.
Power factor	0.67
Maximum intensity	203.
Direction of maximum intensity	below 50°
" " " "	above 30°
Mean hemispherical intensity:	
Upper hemisphere	91.8
Lower hemisphere	129.1
Mean spherical intensity	110.5
Watts per mean spherical Hefner unit	3.68
Watts in arc per mean spherical H. U	2.96
Watts in arc	327.
Globes, character of	opalescent inner.
Carbons	½ inch "Electra."

The lamp was intended for an electromotive force of 104 volts, and the attempt was made to keep it at this pressure, but at the close of the test, the average electromotive force proved to be 103.2. The power factor is due to the inductance of the mechanism, as it has been clearly established by Blondel[10] that, in the arc itself, the electromotive force and current are strictly in phase. It is easy to confirm this fact by current, pressure and power readings taken with reference to the arc alone.

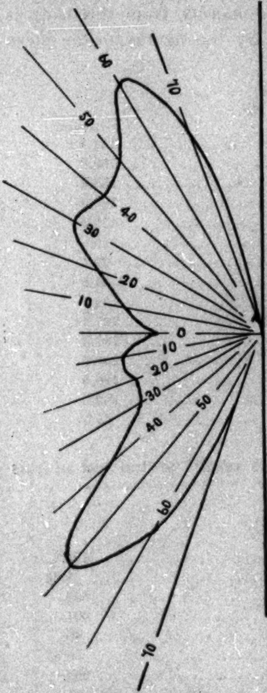

Fig. 4.—Distribution of Intensity from Open Alternating Arc. (Uppenborn.)

The upper and lower lobes of the distribution curve do not yield the same mean values. The discrepancy is due, no doubt, partly to the fact that the bulb about the arc is not of symmetrical curvature, and partly to the greater reflection from the parts of the lamp situated just above the arc. The shape of the distribution curve alters somewhat as the burning of the carbons progresses. The general shape of the curve is not far from that which has been obtained for the open arc. For comparison, one of the several curves taken by Uppenborn[11] for the open arc is here shown. (Fig. 4.) In the enclosed arc the lobes of the distribution curve are shorter, blunter, and extend outward at smaller angles with the horizontal. These changes are due to the shape of the carbon points. It may be pointed out that the distribution curve as plotted above, is a half-section of the mean photometric surface, which is a surface of revolution. The actual photometric surface so far from being a

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[10] Blondel, *La Lumiere Electrique*, vol. 41, 1892.

[11] See Palaz, "Photométrie Industrielle" or translation by Patterson.

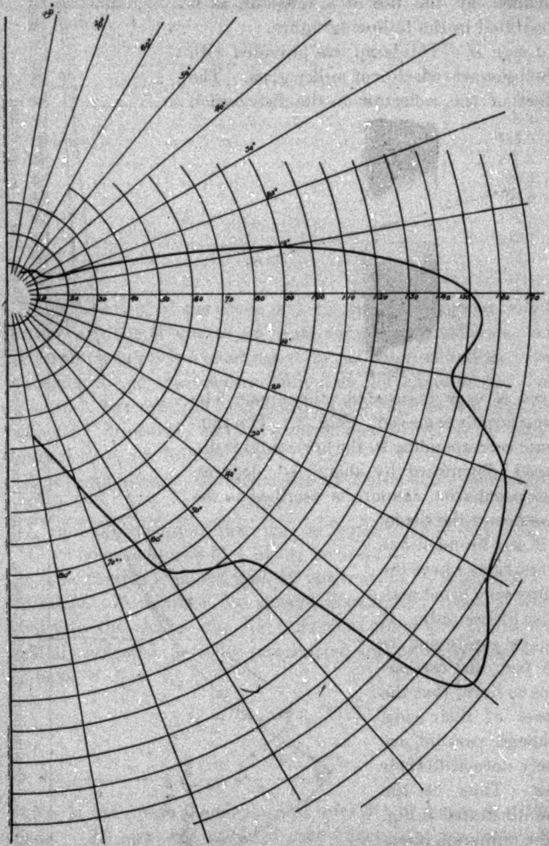

Fig. 5.—Distribution of Intensity. Lamp B.

surface of revolution—is continually swelling, contracting and twisting in a marvellous fashion. As to whether the light thown upward is of value, will depend on whether the lamp is suspended in the open air or under a reflecting ceiling. In most cases considerable benefit will be obtained by the use of a reflector, as is illustrated in the following figure.

Lamp B.—This lamp was provided with a bell-shaped reflector of milky glass. The effect of the reflector on the distribution curve is very noticeable, the upper lobe being largely removed. (Fig. 5.) The minimum corresponding to the horizontal is displaced downward by about 10 degrees. This peculiarity cannot be ascribed to the presence of the shade, as it was found in one or two cases where the lamps were fitted with inner globes only. It is quite surely due to the fact that the carbons so burn, that the planes of their ends, although parallel, are rarely normal to their axes. Thus in the case illustrated in Fig. 6, the minimum intensity might be found displaced either above or below the horizontal, according to the point of view.

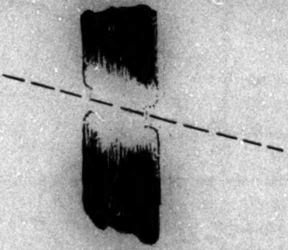

FIG 6.

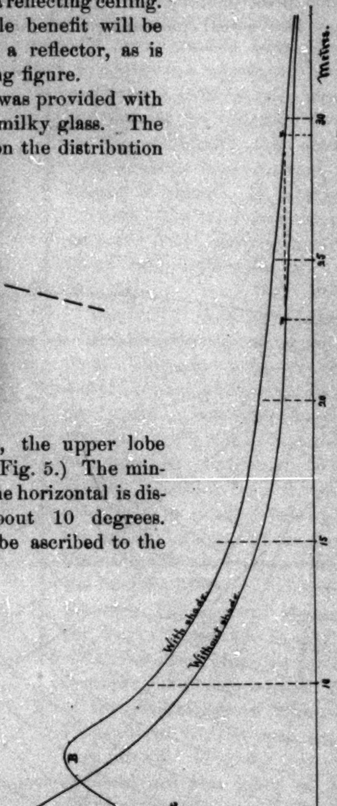

FIG. 7.—Comparison of Illumination on Normal Plane, With and Without Shade, Due to Lamps A and B.

TABLE IV.

Angle. Deg.	Intensity. H. U.
0 horizontal	150.0
10 above	90.3
20 “	18.4
30 “	12.3
40 “	11.5
50 “	9.8
60 “	8.4
10 below	146.5
20 “	171.5
30 “	180.0
40 “	196.0
50 “	112.0
60 “	102.7
70 “	65.4
80 “	46.5

That the effect of the shade is distinctly advantageous will be further evident if curves of illumination be considered. And here unfortunately we must resort to an approximation. Data was taken for an exact determination of the effect of the shade on lamp B, but owing to an accident the figures are not now available. However, certain assumptions permit us to draw a comparison in the following way: Let

I_a = mean intensity of B above the horizontal and without shade,
I_b = “ “ B below “ “ “
I_a' and I_b' be similar quantities as found for B with shade,
I'' = mean intensity of A below horizontal.

Let it be further assumed that 30 per cent. of I_a is absorbed by the shade. Now since the altered distribution from B is due wholly to the shade—the light incident upon the shade being partially reflected, partially transmitted and partially absorbed—we have, if $I_a = I_b$,

$$I_b = \frac{I_a' + I_b' + .3\,I_b}{2};$$

$$= \frac{I_a' + I_b'}{1.7} = 112.2,$$

which is the mean hemispherical intensity of lamp B without shade. If now the radii of the curve B are multiplied by the ratio $I'' : I_b$, we shall have the effect of putting the shade on lamp A.

In plotting the illumination curves shown in Fig. 7, this last was done. Some difference of opinion exists as to whether the ordinates of a curve[12] like this should be the illumination on a surface normal to the ray or on a horizontal plane. In Fig. 7, the illumination on the normal plane has been used, as this quantity serves very well for the purpose of a comparison. It will be noted that the benefit resulting from the use of the shade is most marked at distances remote from the lamp, which is as it should be, since there is no lack of light in the vicinity of the lamp. The following table gives distances at which an equality of illumination will be found:

Unit of normal illumination.	Without shade. Metres.	With shade. Metres.
2.25	6.5	8.2
2.00	7.1	8.8
1.75	7.8	9.5
1.50	8.7	10.4
1.25	9.7	11.7
1.00	11.0	13.3
.75	12.7	15.5
.50	15.2	21.0
.25	22.9	29.4

Lamp C.—This lamp was provided with an outer spherical globe of milky glass. The data obtained for the distribution of intensity were as follows:

TABLE VI.

Angle. deg.	Without globe. H. U.	With globe. H. U.
0 horizontal	132.0	37.2
10 above	137.0	42.8
20 "	158.0	42.7
30 "	122.0	38.4
40 "	85.0	28.7
50 "	30.4	17.4
60 "	18.0	7.7
10 below	126.0	36.1
20 "	133.8	32.6
30 "	140.7	31.4
40 "	117.0	30.0
50 "	120.0	28.2
60 "	90.0	30.7
70 "	68.0	29.8
80 "	47.5	24.7

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[12] It is probable that the unit of illumination most consistent with the C. G. S. system is *H. U.* / *cm.*^{2}. This unit is many times too large, however, and throws the numerical expression for an illumination far into the decimal places. The unit *H. U.* / *m.*^{2}, obtained by multiplying the first named unit by 10^{-4}, is preferable in this respect.

The foregoing values are plotted in Fig. 8. This distribution is in some respects anomalous. The larger area below the horizontal is due to the presence of a narrow reflector placed inside the outer globe. No reliable reason can be given for the presence of the maximum at 20 degrees above. It may be due to

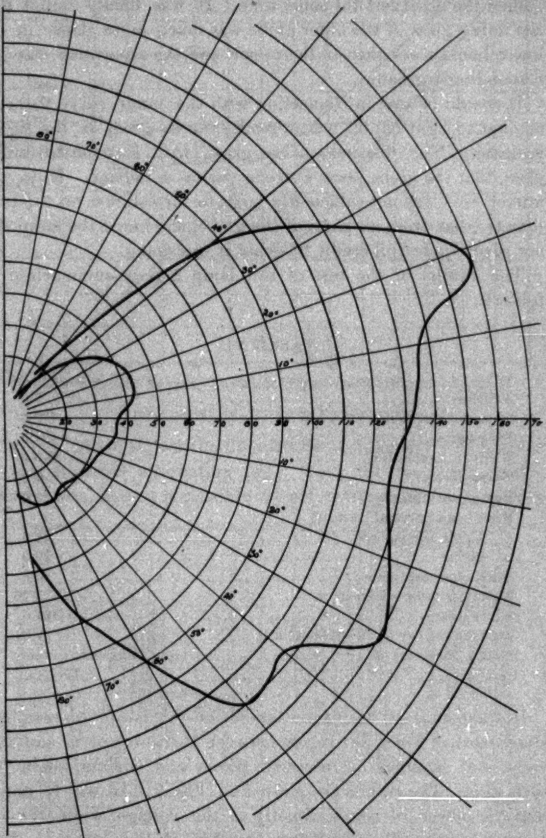

FIG. 8.—Distribution of Intensity. Lamp C.

some lack of accurate centering of the carbons. The peculiar shortening of the radii of the inner curve in the lower angles, baffled the observers for some time. It was finally found that the milky glass of the outer globe was much more dense in the lower hemisphere than in the upper, and the absorption was correspondingly greater.

It should be said in connection with the inner curve that the amount of light cut off was in reality not so great as the figure indicates. The dispersion is so great, with a globe of milky glass, that the globe plays a strong part as a radiant. Now, the mirror used was not sufficiently large to furnish rays on the photometer disk from all parts of the globe, and hence the lamp was not given quite full credit for what it was doing.

The results of the test of this lamp may be summarized as follows:

TABLE VII.

Volts	110.0
Amperes	7.0
Apparent watts	770.0
True watts	484.0
Watts in mechanism	116.0
Power factor	0.63
Maximum intensity	158.0
Mean hemispherical intensity :	
Upper hemisphere	68.5
Lower "	99.0
Mean spherical intensity	83.8
Watts per mean spherical H. U	5.76
Watts in arc	364.0
Watts in arc per mean spherical H. U	4.34
Globes, character of	opalescent inner.
Carbons	"Electra."

In the course of the measurements on this lamp, the terminal electromotive force was varied between the limits of 87 and 118 volts, and readings of intensity, power and current taken for each step. The results are plotted in Fig. 9. It will be noted that the power increases directly as the voltage; while the intensity is a rapidly increasing function of the voltage. The change in the current is slight. The high intensity at high voltage is partly due to the longer arc, but more especially to the higher temperature of the carbon points and consequent increased surface in the craters.

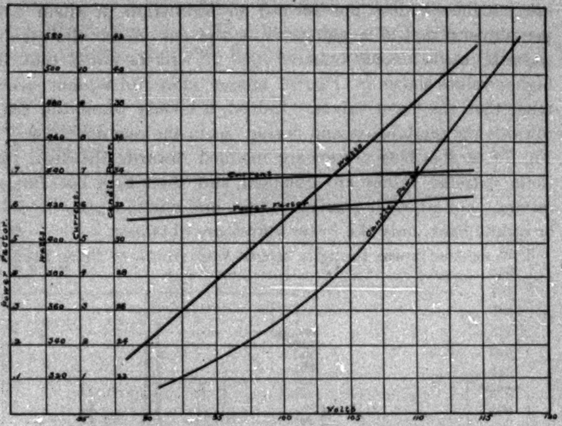

Fig. 9.—Effect of Varying Impressed Electromotive Force. Lamp C.

Fluctuations in the Intensity.

In Fig. 10 are shown the fluctuations in intensity which occur in the enclosed alternating arc. With the recording device already described, it is possible to get settings of fair accuracy

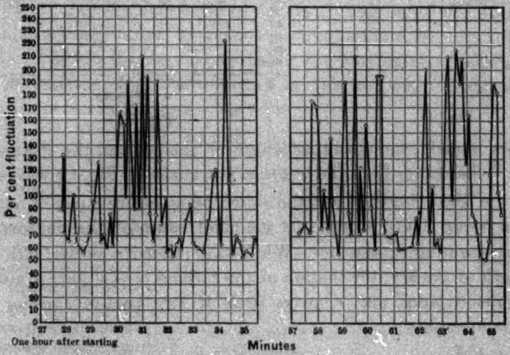

Fig. 10.

with a considerable degree of rapidity, as is here shown. The large changes in intensity are plainly noticeable in watching the arc, but the eye does not furnish an estimation of them comparable with that to be gained from the curves, for the psychophysical reason already referred to. It will be noted that the higher values shown in Fig. 10 are of more infrequent occurrence than the lower values. Indeed, it is only when the arc is towards the photometer and flaring out in the manner shown in Fig. 11, so that both craters are inclined towards the disk, that these extreme values are obtained, and then they last but an instant. For all other positions of the arc, whether on the sides or on the back, only the lower values are obtained.

Two causes, it was thought, might contribute to these fluctuations, namely, the changing length of the arc and the "wandering" character of it. To test this, the curve in Fig. 12 was taken with a fixed length of arc, the clutch being entirely out of action. The result plainly shows that the chief cause of the fluctuations is the hunting of the arc. While the intensity varies with the length of the arc, the motion of the carbons is so slight, in a well-regulated lamp, that it plays little if any part in causing the variations shown.

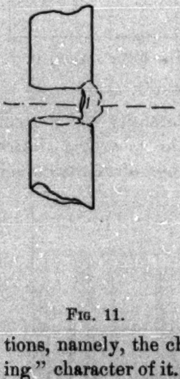

Fig. 11.

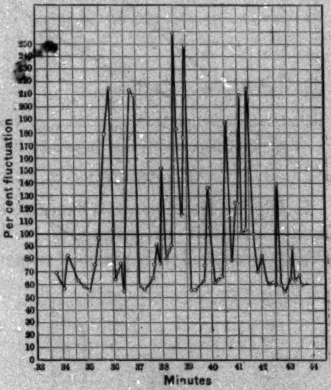

Fig. 12.

Comparison with the Enclosed Direct-Current Arc.

Lamp D.—Measurements were made on a direct-current lamp of the same manufacture as lamp A, with a view of bringing this type of lamp under conditions identical with those of the tests of the alternating arc. The lamp was fitted with an inner opalescent globe only. The distribution of intensity is as follows:

TABLE VIII.

Angle. Deg.		Intensity. H. U.
0	horizontal	218
10	above	165
20	"	237
30	"	159
40	"	144
50	"	121
60	"	60
10	below	410
20	"	391
30	"	341
40	"	377
50	"	369
60	"	416
70	"	172
80	"	106

In Fig. 13, these values will be found plotted in the usual manner. This curve was taken with great care and may be taken as typical of the distribution due to the enclosed arc fed by a direct current. The peak at 20 degrees above is due to the small crater of the negative carbon. Here also the depression in the curve due to the low luminosity of the arc is found displaced by 10 degrees above the horizontal. This lamp will give an excellent illumination at points somewhat remote, because the curve is so full in the region just below the horizontal. A shade would still further improve the lamp in this respect. Detailed results are given in the following table:

TABLE IX.

Volts	108.
Amperes	4.96
Watts	536.
Watts in mechanism	152.
Maximum intensity	416.
Mean hemispherical intensity:	
Upper hemisphere	106.5
Lower hemisphere	288.
Mean spherical intensity	197.3
Watts per mean spherical H. U.	2.72
Watts in arc	384.
Watts in arc per mean spherical H. U.	1.95
Globes	Opalescent inner
Carbons	"Electra."

As regards efficiency, or better *economy*, say in watts per Hefner unit, the direct current lamp is superior to its alternating

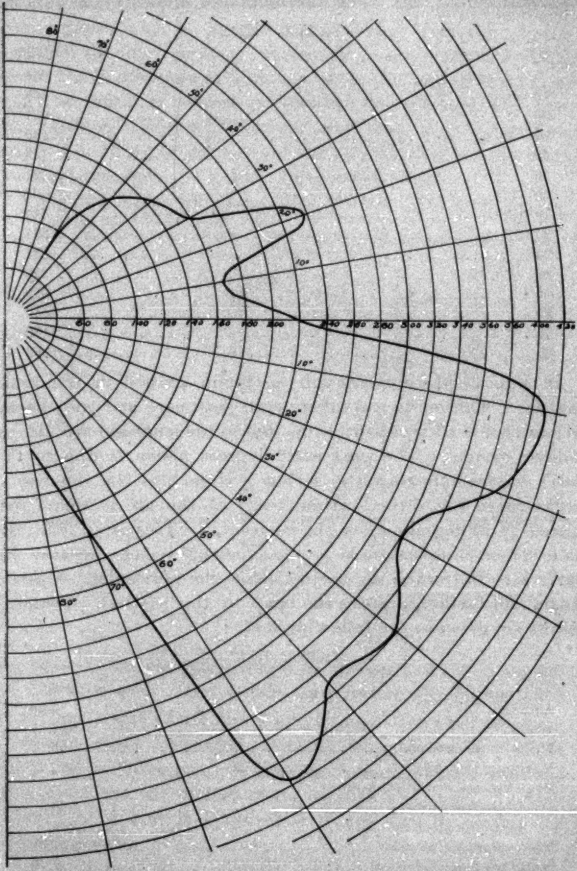

FIG. 13.—Distribution of Intensity. Lamp D. (Direct Current.)

current competitor. The performance of lamp A was the best found in these tests, that of lamp C the worst. The other lamps tested showed different degrees of economy lying between the limits set by these two.

The writers feel justified in saying that the lamps of low economy could, by improvement in mechanism, be brought to a performance equal to that of lamp A. All the lamps tested, with one exception, were furnished with the same brand of carbons. With similar carbons and similar globes, a difference in economy must be attributed largely to the mechanism.

If the alternating arc be regarded apart from any regulating device, the physical reasons for its poorer qualities as a light source are to be found in the lower temperature of the glowing points and in the diminished area of crater surface. In the direct current arc, we find two bright surfaces of unequal area and of widely different temperature. In the alternating current arc we find two bright surfaces of the same area and of the same temperature. According to Rossetti, the temperatures in the first case are 3900 C. and 2700 C. Now the points in the alternating arc are as much positive as negative, and hence, whatever the unknown law connecting the temperature of glowing carbon with the intensity of the light due to it, we should expect the mean spherical intensity of the alternating arc to have a value intermediate between the values of mean hemispherical intensity for the upper and lower lobes of the distribution due to the direct current arc. A comparison of lamps A and D shows this point, although the total power is not the same. If the power consumption of the alternating arc were raised from 327 to 384, it is very probable that the mean intensity would be found raised from 110.5 to a considerably higher intermediate value.

The values of the intensity of the direct-current lamp are lower than those found by some earlier observers. In fact, the enclosed arc has been reported in some instances as quite equal to the average open arc. It is difficult to see how these results can be accurate for a lamp fitted with an opalescent globe. The results of a test recently reported by Nichols agree closely with those given for the direct current lamp in this paper.

Electrical Laboratory, Purdue University,
Lafayette, Ind., September, 1898.

A Paper presented at the 15th General Meeting of the American Institute of Electrical Engineers, Omaha, June 29, 1898, President Kennelly in the Chair.

SOME TELEPHONE DISTURBANCES FROM ELECTRICAL GENERATORS.

BY GEORGE D. SHEPARDSON.

The modern tendency toward concentration of power plants and the use of larger units has caused some unexpected secondary results. In one of our western cities the street railway company recently built a modern power-house with seven directly connected generators, two direct current generators of 700 K. W. capacity which feed directly into the trolley lines, and five three-phase 700 K. W. alternators which drive five rotaries located at three sub-stations. The rotaries displace three steam equipments with a number of 175 K. W. generators. At about the same time in the same city the principal lighting company displaced the steam equipment in one of its direct current constant potential stations by rotaries driven by three-phase currents from its main station. When the rotaries were put into service, the telephones of the city were at once greatly disturbed by a loud roaring noise which seriously interfered with their satisfactory operation and which even made many telephones useless. While the telephone company was attempting to locate the cause and find a remedy for the troubles, the lighting company found that it also had troubles of its own, as the constant potential arc lamps which had been burning quietly, now began to hum and roar as if operated by alternating currents.

The subject promised to be of much interest, and was studied from an independent standpoint at the University of Minnesota by Instructor F. W. Springer and the writer. While the ground has not yet been entirely covered, enough of interest has developed to warrant a preliminary report with the hope that others may find opportunity and interest to carry on further studies along the lines suggested.

No doubt much of the work here reported has been done before in the company laboratories, but such work seems not to have been published.

In order to work more intelligently, a preliminary search was made to discover the disturbances that had been met by telephones before, and their names were found to be legion.

The marvelous sensitiveness of the telephone, exceeded only by that of the galvanometer, has made it unusually subject to disturbing influences. Coming into public use at about the same time as the electric light, its lines were extended more rapidly at first and many towns boasted of telephone exchanges long before the advent of electric lighting plants. When the lighting plants were put into operation later, the telephone lines theretofore operating in blissful peace and quiet, were now seriously menaced as one of their engineers aptly quoted[1] by a "pestilence that walketh in darkness" and by "destruction that wasteth at noonday." Hardly had the lines been freed from the disturbing influence of the direct current incandescent and the more troublesome arc circuits, when the alternating current system took the field with its widely scattered lines and its wider range of induction and the way of the telephone manager was thereafter indeed as hard as that of the transgressor should be. Hardly had the telephone adjusted itself to the new source of disturbance when still another enemy arose in the shape of the electric railway, which, metaphorically speaking, demanded that the telephone, like the Chinaman, should "get off the earth." Many legal battles have been fought with varying success, but the general conclusion seems to be that no one interest owns the whole earth, and that in case of interference the weaker must look out for its own protection. The remedies that have been proposed for obviating or neutralizing telephonic disturbances are too many even to catalogue in a paper treating principally with causes. As early as 1883, there were 200 or more patents for preventing induction, and the later years doubtless have been even more prolific.

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[1] Lockwood, National Telephone Exchange Association, Sept., 1883 *El. World*, 12: 142. Lon. *El. Rev.*, 23: 441. West. Electrician, 3: 149. N. Y. *El. Engineer*, 7: 485. Walker, Lon. *El. Rev.* 12: 278. *El. World*, 1: 344. See also Lon. *El. Rev.*, 34: 345. 32: 692. N. Y. *El Engineer*, 15: 474.

Telephone engineers have devoted much time and attention to the various causes for the noises that disturb the telephone and have specified them somewhat as follows: Long telephone lines are subject to the same disturbances[2] that affect the less sensitive telegraph. Some of these are of more or less constant strength and do not make a noise in the telephone, but only alter its sensitiveness by strengthening or weakening the permanent magnet. Such are the regular earth currents caused by the rotation of the earth, or those caused by electro-chemical action due to the differences in the soil at the ends of the line, or to differences in the composition or cleanness of the earth-plates, or thermo-electric currents due to differences of temperature at differents parts of the line. The irregular currents that sometimes affect telephones may be caused by induction from the earth's magnetism as the wires swing back and forth in the wind, from induction as wires of different circuits approach and recede while swinging in the wind, by differences in the height above the earth in different parts of the line, by static charges from passing clouds or rising vapors, by changes in the electric state of the atmosphere, possibly by electromotive forces due to earth tremors, by mechanical vibrations of the wires, by a sort of microphonic action at loose joints, by changes of resistance of line due to temperature. Such disturbances seem to become less when the insulation of the line is low.

Disturbing currents from other wires are found to come by leakage and by induction, both electro-static and electro-dynamic, those being overcome by careful insulation and transposition of circuits. The disturbing currents are found to be greater from alternating or arc light circuits than from constant potential direct current circuits; open circuit arc machines are worse than closed coil machines, the noise becoming less as the number of bars in the commutators increases, and becoming greater[3] as the voltage increases.

That much of the trouble from other circuits comes by electrostatic induction was proved by Mr. J. J. Carty in his papers before the New York Electric Club[4] and before this[5] body. His conclusions have been substantiated by other experimenters, such as [6]Pierard, [7]Kennelly, [8]Bennett, [9]Dresing and Gulstad [10]Dunbar, and others. That much of it comes by leakage is a matter of daily observation.

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[2] Lockwood, National Conference of Electricians, Sept. 12, 1884. Proceedings, p. 226. *El. World*, 4: 169.

[3] *El. World*, 19: 274.

[4] Carty, New York Electric Club, Nov. 21, 1889. *El. World*, 14: 361. Lon. *El. Rev.*, 25: 651. Lon. *Electrician*, 24: 122. N. Y. *El Engineer*, 9: 12. *West. Electrician*, 5: 282. *Elek. Zeit*, 11: 144.

The trouble from electric railway lines is generally considered as coming primarily and principally from the use of the ground return. If the railway currents were perfectly smooth and of uniform strength, it is generally agreed that they would not cause noises in the telephone, but would make them less sensitive. The irregularities and fluctuations in the railway current have been attributed to various causes, such as imperfect commutation[11] at the dynamos, imperfect connection between the trolley wire and supports, variable contact between the trolley and wire or between[12] the wheels and rails, lubrication[12] of the trolley, sparking at the motor[13] brushes or trolley or rails, variable speed of cars, motion of track[14] due to passage of car, to the motion[12] of the car, to noisy gearing[15], to vibration[13] of the motor. Strecker[16] says the noise varies with the voltage. Cardew[13] says it varies with the winding of the armature. There is probably more or less of disturbing influence from each of these alleged sources.

At first thought, the ordinary trolley of the American pattern would seem to give as certain contact as the shoe or harp used

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5. Carty, TRANSACTIONS, March 17, 1891. *El. World*, 17: 241, 276. Lon. *Electrician*, 26: 685, 705. Lon. *El. Review*, 28: 462. N. Y. *El Engineer*, 11: 366, 451. *West Electrician*, 8: 181, 210. N. Y. *El. Rev.*, 18: 82.

6. Pierard, *L'Eclairage Electrique*, 2: 121, Jan. 19, 1895, 10: 355. Feb. 20, 1897. *El. World*, 25: 181; 29: 362.

7. Kennelly, *El. World*, 17; 277. Lon. *Electrician*, 26: 763. Lon. *El. Rev.* 28: 747. N. Y. *El. Engineer*, 11: 450, 511, 547.

8. Bennett. Lon. *Electrician*, 26: 768.

9. Dresing and Gulstad, Lon. *El. Rev.*, 28: 589, 643, May, 1891.

10. Dunbar, *El. World*, 23: 83, 115.

11. Lon. *Electrician*; 36: 725; 37: 52. *El. World*, 12: 324. Lon. *El. Rev.*, 34: 339.

12. Wietlisbach, Lon. *Electrician*, 36: 725. N. Y. *El. Engineer*, 21: 388, 414, 440. *El. World*, 27: 438, 578. *Elek. Zeit.*, 17: 252. Perry, N. Y. *El. Engineer*, 9: 244. Van Vloten, *L'Eclairage Electrique*, 12: 415.

13. Cardew, Lon. *El. Rev.*, 33: 742. Lon. *Electrician*, 32: 236.

14. West, *Elek. Zeit.*, 17: 263. April 30, 1896. Lon. *El. Rev.*, 38: 640. Lon. *Electrician*, 37: 52.

15. Preller, Lon. *Electrician*, 36: 338, 557. *El. Railway Gazette*, Feb. 1, 1896. *El. World*, 27: 132, 293. *L'Eclairage Electrique*, 6: 411. Perry, N. Y. *El. Engineer*, 9: 244.

16. Strecker, *Elek. Zeit.*, 13: 128, Mar. 4, 1892. *El. World*, 20: 19.

on certain roads, yet eminent engineers, such as Wietlisbach[12], claim superiority for the sliding harp or bar, and appeal to experience. Lord Kelvin[17] states as his opinion that two or three wheels or a brush would obviate much of the difficulty. The most plausible explanation for the observed fact that roads using harp or bars disturb telephones less than those using wheels for contact with the trolley wire, seems to be that with the harps or bar trolleys the trolley wire need not be so accurately centered above the track as when a trolley wheel is used, therefore the line need not be supported at so frequent intervals and need not be drawn up so tightly. The tighter wire more easily gets thrown into rapid vibration, which in turn causes a considerable variation in the pressure between the trolley and the wire, hence setting up a microphonic action that affects the telephones. The lubricant on the trolley probably acts in a similar way. Experiments by West show that there is quite a considerable variation in the resistance between the car wheels and the track, even with a comparatively clean rail; and he infers from this that some of the telephonic disturbance is due to microphonic action at the wheel as well as at the trolley. The noise also depends upon the nature of the track, being greater on a hard roadbed than on one cushioned. This is thought to be due to variations in the surface resistance between the rails and the surrounding earth as the car passes. Experiments by Behn-Eschenburg[18] seem to show that the noise is not due to such action at the rail, wheel or trolley, for by cutting out the motors and sending current from the trolley through a rheostat he found an entire absence of noise; this simply proves, however, that such source of noise is very small as compared with that from the motors. Another source of microphonic action that seems at least as important as the two preceding is that due to the vibration of the brushes of the motors on account of the commutator not being truly cylindrical, or on account of the brushes being set too nearly radial with insufficient pressure so that they chatter. The great telephonic disturbances noted when the brushes of generator or motor are sparking may be microphonic or may be due to another cause to be noted later. That the noise varies with the speed of the motor is evident to all who have had occasion to use telephones with earth or common return in cities with electric cars. Following out this lead it seems reasonable that noisy gears disturb telephones more than quite ones, because quiet gears allow a more uniform motion of the motors, while noisy gears involve an uneven rate of transmission and hence an uneven speed of armature. A similar reason may account for the claim[14] that motors with chain connection create less disturbance to telephones than those having gears for transmission.

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[17] Kelvin, Lon. *El. Rev.*, 33 : 742. Lon. *Electrician*, 32 : 236.

[18] Behn-Eschenburg, *Elek. Zeit.*, 17 : 173, July 16, 1896. *El. World*, 28 : 158, 173.

That a large share of the disturbance is caused by the motors themselves is seen from the well-known fact that the starting of a car is accompanied by a distinct rumble that increases in pitch as the car comes up to speed until the noise becomes blended in the general confusion at the higher pitch. The noise is directly connected with the brushes and commutator, as is evidenced by the uniform pitch of the sound in the telephone and that heard directly from the singing of the brushes. That it is affected also by the design of the motor is shown by the well remembered action of the early railways; when the early Sprague railway motors were changed from 56 to 72 armature coils, the noises in the telephone were greatly reduced and one could easily tell what kind of motor was on an approaching car. Various reasons have been assigned for the cause of the noise from the brushes. The most common one is that the resistance of the motor changes as commutator bars come under the brushes, so that one or more coils are short-circuited and cut out of the circuit. Others think it may be due to "feathering" of the brushes[19], which allows a continual and uncertain change in the number of armature coils actually in the circuit.

When the street railway company referred to at the beginning of this paper changed over to the new arrangements for power, the great increase in the noises in the telephones was attributed to the fact that the new generators and rotaries had toothed armatures, whereas the old armatures had smooth cores and were surface wound. The greater self-induction in the toothed machines was supposed to cause irregularities or "wiggles" in the current. Some thought that the speed varied slightly in different parts of each revolution, while others thought that in some way part of the alternating current managed to get over into the direct current circuits without being transformed.

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[19] Wietlisbach, Lon. *Engineering*, Aug. 14, 1896. *Elek. Zeit.*, 17: 582. *El. World*, 28: 283, 313.

In order to learn the truth of the matter, a number of experiments were tried. That no considerable part of the noise came from any lack of uniformity in the speed of the rotaries was proved by the absence in the telephone of any tone of a pitch equal to the product of revolutions by poles of the rotaries. A variation of speed with load was noticeable when each alternator was driving its own rotary, but this was largely obviated when the alternators were operated in parallel. In order to discover whether by any means part of the alternating current could or did get over to the direct current lines, observations were made upon the constant potential arc lamps operated by the rotaries of the lighting company. It was found that the hum of the arc lamps did not at all correspond with the frequency of the current, but that it did correspond exactly with the hum of the brushes, the pitch of which was equal to the product of revolutions by commutator bars. The cause of the noise in the telephones and arc lamps seemed therefore to be connected in some way with the commutation of the current at the direct current brushes.

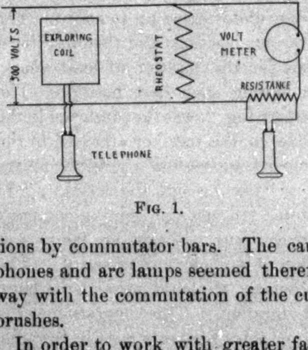


FIG. 1.

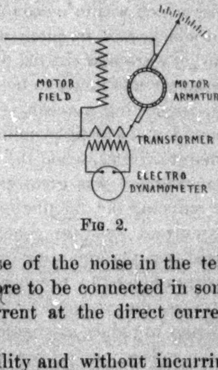


FIG. 2.

In order to work with greater facility and without incurring liability of interfering with the regular working of the commercial plants of the railway, lighting or telephone companies, further experiments were carried on in the electrical engineering laboratories of the University of Minnesota, where most of the conditions could be accurately reproduced and modified one at a time.

Preliminary experiments were first tried with a telephone receiver connected to an exploring coil of 150 turns wound on a rectangular frame approximately 8″ long and 7″ wide, with a groove 1″ wide. This exploring coil was hung between the two main service wires leading to a 500-volt 40 H. P. motor connected with the power station. When a current of seven amperes from the power circuit was sent througha water rheostat, Fig. 1, a clear singing noise was noted in the telephone, which noise was attributed to the generators at the power-house. To make sure that the noise was not due to the water rheostat, a second test was made by shunting the receiver around a small resistance in series with a high-resistance voltmeter. The same noise was heard and in addition definite beats could be distinguished at the rate of about two per second. These were thought to be due to interference between the generators at the power-house, where there were four power machines, one of which was of different make from the others.

The receiver was then connected with the exploring coil between the service wires and the motor started. The original sound from the generators was now entirely obscured by a loud noise which was in unison with the singing of the motor brushes and which rose in pitch as the motor came up to speed. The brushes were now shifted to various positions and the noise from the motor was found to be least for the position of least sparking, suggesting a means for finding such best position. The coarse coil of a 30-light transformer Fig. 2. was then inserted in the armature circuit, when the noise in the receiver attached to the exploring coil was greatly reduced, suggesting a possible means for reducing the fluctuations or "ironing out the wrinkles" in the current from the generators. In fact the lighting company found that the humming of its constant potential arc lamps was greatly reduced by the insertion of a choke coil in series. (The noise was also reduced by tightening all loose parts of the lamp in order to reduce mechanical vibration.) This suggests that the choke coils wound on heavy iron cores formerly used in Sprague railway power houses between the lightning arresters and the bus bars were more useful in reducing the pulsations of the current than they were for choking back the lighting.

A Weston A. C. voltmeter was then connected to the fine wire coil of the transformer and it was found to read seven volts when the armature current was 18 amperes. In order to make sure that there was no mistake, two sets of readings were taken while the brushes were shifted to various positions, one set with the motor armature taking about six amperes and the other with about 18 amperes, it being difficult to keep the current and speed exactly constant while shifting the brushes. A scale was attached to the brushyoke and divided so that one division represented a shifting of the brushes equal to the width of one commutator bar. A number of readings were then taken, the means of which are given in Table I. The voltmeter readings are not very accurate, since they all come on the lowest part of the scale where it is not closely divided.

TABLE I.

Effect of Current Strength Upon Fluctuations Through Transformer With Iron Core. 500 Volt-Motor.

Position of Brushes.	Volts on Secondary.		
	3 Amperes.	6 Amperes.	18 Amperes.
3	—	—	12.5
3½	—	15	8.5
4	—	6	5.5
4⅝	11	7	3
5	9	6	2.5
6	8	6	4.5
7	8	7	5
8	8.5	8	7.5
8½	—	11	9
9	11	—	—

In Table I. the brushes have forward lead in position 3 and backward lead in position 8. It is seen that for every position of the brushes the voltage on the secondary is higher with the smaller current than with the larger. This did not seem right, and another test was made with the telephone and exploring coil. In this case the noise in the telephone was directly proportional to the current in the armature, as would have been expected. The contrary results with the transformer were then attributed to the fact that the iron core of the transformer was so highly saturated by the current of 18 amperes that the pulsations had less effect than those of the six ampere current and still less than those with the three ampere current, although the former were actually much greater. Similar results were obtained with other transformers and it was found misleading to have any iron in the transformer. Two coils were then wound on a cylindrical wooden core 14″ in diameter, one coil of 28 turns of No. 10 B &

S G and one of 342 turns of No. 20 B & S G. These were arranged so that the coarse coil in series with the armature remained stationary while the other was movable along a pine stick parallel to their common axis The telephone receiver was then connected to the fine wire coil and the armature current was sent through the coarse wire coil. By moving the fine wire coil along the stick it was intended to find the position where the sound in the telephone would disappear. But the arrangement proved to be too sensitive even when only one turn of the coarse wire was left in circuit and the fine wire coil was moved 100″ away, the sound from the motor still being quite distinguishable. As at that time the writer did not recall the differential method of opposing the action of the first coil by that of a third in which a uniform alternating current might be sent from an independent source, and as later it was questioned whether the balance would be reliable because the pulsations at the armature were not sine functions, it was decided to make use of a sensitive electro-dynamometer for measuring the currents induced in the secondary of the air core transformer. After some preliminary work the two coils were arranged on a common axis, being separated by the distance of one inch. The fine wire coil was connected to an electro-dynamometer having a resistance of 100 ohms and being free from metallic masses near the coils.

The 500-volt machine was then operated as a motor, and two sets of readings were taken with the air-core transformer and electro-dynamometer to compare with those taken with the iron core transformer and the Weston voltmeter. The averages of ten readings taken at each position of the brushes are given in Table II., from which it is seen that except for the extreme forward position of the brushes the pulsations in the current are greater with 13.3 amperes than with 6.3 amperes, as might naturally be expected. From later experience it is believed that inaccuracy in setting the brushes or a possible slight displacement of the index would account for the apparently greater deflections by the smaller current at positions of forward lead.

While the iron core transformer was in series with the armature, another experiment was tried to discover the effect of staggering the brushes. The load on motor was kept constant and two runs were made, one with the brushes set normally, all leaving commutator bars simultaneously; while in the second run, the positive brushes were left in their usual position while the negative brushes were blocked out so that their toes were at the middle of a bar when the toes of the positive brushes were just leaving a bar. The brush yoke was then moved to different positions and corresponding readings were taken on the voltmeter in the secondary circuit. The readings given in Table III. show that staggering the brushes effects a considerable reduction in the irregularities of the current. In the machine under experiment the carbon brushes spanned two whole bars of the commutator, so that displacing one set only a half bar had less effect than would be expected if the brushes covered only the width of one bar. That the pressure upon the carbon brushes has a considerable effect upon the smoothness of the current from the generator is shown by an experiment in which the electro-dynamometer gave a deflection of 53.5 millimeters when the pressure against the carbon brushes was only moderate, while it was reduced to 7.4 by tightening the springs, the current remaining 6.6 amperes in both cases. The time at our disposal did not allow further tests along this line, but it suggests an interesting field for studying how the smoothness of the

TABLE II.

Effect of Brush Position Upon Fluctuations Through Transformer With Air Core. 500 Volt-Motor.

Position of Brushes.	E. M. F. on Secondary.	
	6.3 Amperes.	13.3 Amperes.
4	—	30.3
4⅜	26.6	(22)
4½	(22)	20
4⅝	19.1	(17.5)
5	14.1	12.5
5½	12.4	14.1
6	11.3	14.2
6½	9.2	12.9
7	12.8	13.4
7½	12.8	15.2
8	13.4	18.7
8½	15.4	20.7
9	22	26.1
9⅜	37.3	—

current is affected by width of brushes, by various kinds of brush such as carbon, copper, leaf, gauze, and the various anti-sparking high resistance materials on the market. It seems probable also that the best pressure and best angle for the carbon brushes might be studied to advantage by the telephone or electro-dynamometer method.

TABLE III.

Effect of Staggered Brushes Upon Fluctuations Through Transformer With Iron Core. 500 Volt-Motor. Taking 5 Amperes.

Position of Brush Yoke.	Volts on Secondary.	
	Brushes Opposite.	Brushes Staggered.
2½	—	20
3	20	8
3½	11	—
4	8	6.5
5	7	6.5
6	7	6
7	7	7
8	—	7
8½	9	8

In the experiments with the 500-volt motor it was thought that perhaps the fluctuations of the generators were affecting the results, so that it was decided to examine a generator working on loads of various kinds and amounts. As at that time the University lighting plant had shut down for the summer, it was impracticable to drive the 500-volt machine as a generator by one of the other machines, and it was therefore used as a motor to drive an Edison generator upon which further experiments were made. This machine has a smooth armature core and so is not strictly comparable with the toothed machines whose pulsations disturbed the telephones referred to at the outset, but it was believed that from its study, results could be obtained that would throw some light upon the general subject of the disturbances.

The Edison dynamo was run at a speed of 1265 revolutions per minute, so that the product of revolutions by commutator bars, 1265 x 50, would equal a similar product for the 500-volt motor which had 96 bars and ran at 660 revolutions per minute. The results with the two machines are not strictly comparable because one was operated as a motor and the other as a dynamo, the motor operating at 500 volts and the dynamo at 93 volts with one current and at 67 volts with a larger current. The normal voltage of 110 could not be maintained on account of the low speed adopted in order to keep the frequency the same. Sets of readings were then taken with the Edison dynamo delivering 6.3 and 12.6 amperes through a non-inductive resistance while operating with the fields excited first by a storage battery, then as a shunt machine, then as a highly over-compounded machine.

TABLE IV.

Effects of Field Excitation And Armature Current Upon Fluctuations Through Air Core Transformer. Edison Dynamo. On Non-inductive Load.

Position of Brushes.	Field Excited by Battery.		Self-Excited, Shunt.		Self-Excited, Compound.
	6.3 Amperes.	12.6 Amperes.	6.3 Amperes.	12.6 Amperes.	12.6 Amperes.
3	—	157.6	319	—	214.5
3½	—	118.7	310	—	228.5
4	47.1	65.7	170.4	357	131.3
4½	29.2	36.1	114.2	130	55.2
5	7.5	15.3	37.9	62.8	20
5½	1.8	7.6	6	20.6	5.5
6	1.5	5.1	0	3.9	2
6½	1.4	2.0	0	2.1	1.5
7	3.5	2.8	1.4	17	4
7½	9.4	11.9	13.6	34	12.4
8	26.9	13	41.3	74.3	27
8½	30.6	31	145	208	34.1
8¾	—	—	—	292	—
9	43.7	91.3	228	?	54.3

The electro-dynamometer readings given in Table IV. are the means of from 4 to 14 readings taken at the various positions. Examination of the figures shows that for the same current, the pulsations with the low voltage Edison smooth core dynamo are always less than those with the 500-volt with toothed armature. It is a source of regret that no machines were readily available having similar voltage and capacity and differing only in the armature core. It is hoped to obtain access to such similar machines for further study. It will be noted further that with a given excitation of field, the fluctuations of current are always greater with the larger current. Generally speaking, the fluctuations are less with the fields excited by current from the storage battery than when self-excited, also the fluctuations are much more with the shunt machine than with the compound. During the experiments, a periodic wavy sound was noted in the telephone. This was traced to the slight end motion of the armature and was stopped by adjusting the thrust bearing.

A preliminary experiment with the fields separately excited showed that an inductive load had the effect of smoothing out the fluctuations so that they became insensible. When the current was sent into the fields of an alternator (whose armature was at rest), the electro-dynamometer gave no deflection whatever for any safe position of the brushes. The telephone receiver was then substituted for the electro-dynamometer in the secondary circuit of the air-core transformer whose primary was in the main circuit, and no sound was perceptible until the brushes were moved to the extreme forward "position 2," where the sparking was vicious.

The smallness of the pulsations when the dynamo was excited by the battery current suggested that the fluctuations affected the field current. A telephone receiver without any connections was placed near the pole-pieces of the dynamo and immediately a roaring noise was heard which was in exact unison with that of the brushes. This noise in the receiver seemed to be of the same intensity whether the machine was delivering 12 or 6 amperes or whether the external circuit was entirely open. The only difference one could detect in the telephone was a slight lowering of pitch corresponding with the lowering of the speed of the dynamo when the load was thrown on. The brushes were then raised and the fields excited by the battery; no noise was heard. But as soon as one brush was lowered upon the commutator, the familiar roaring was heard. This noise was greater when the one brush was moved toward the sparking position. The noise was also increased when a second brush was lowered upon the opposite side of the commutator. For any given position of the brushes, the volume of the noise was entirely unaffected by the conditions of the outside circuit. In order to learn whether this disturbance by the current in the coils short-circuited by the brushes was simply electro-dynamic or whether it was electro-magnetic, the telephone was moved to various positions. In each case the noise was greater in positions where the ordinary magnetic leakage from the pole-pieces was known to be greatest. The sound from the short-circuited armature coil alone could not be distinguished near the head of the armature. A high resistance galvanometer coil was next connected with the telephone and moved to various positions about the dynamo. The results uniformly corroborated those obtained with the telephone directly. The currents in the coils short-circuited by the brushes therefore affect the magnetism of the iron of the field magnet, although one would hardly expect that sluggish cast-iron and solid wrought-iron would respond to 1054 complex cycles per second. To make sure that the magnetism of the whole circuit did actually pulsate, the external circuit of the dynamo was opened, all the brushes were raised, battery current was sent through the field coil and the telephone was shunted around part of the regulating rheostat in the field circuit. The telephone remained quiet until one brush was lowered, when the same roaring was noted again, showing that the field current was caused to pulsate by the short-circuited armature coils. This phenomenon is akin to that noted with alternators whose armature reaction causes the field current from the exciter to pulsate in unison with the alternating current.

The previous experiment seems to show that the fluctuations in the current do indeed come from some action of the brushes and commutator; but further, that it is not due entirely, perhaps not at all, to the simple cutting of an armature coil out of the main circuit. It is due rather to the more roundabout action of the current through the short-circuited coil, causing pulsation in the strength of the whole field and so affecting the total E. M. F. induced in the whole armature. In the case of the shunt dynamo, the magnetic field fluctuates not only from direct influence of the current in the short-circuited coil, but also from the fact that this in turn affects the current in the field and thereby again affects the total magnetization. Later measurements of the instantaneous values of the external current at different epochs of the pulsation seem to indicate such action. The effect of the series coils seems to be a smoothing out of the fluctuations, the self-induction of the coil having more effect upon the current passing than upon the magnetization.

The pulsations are greatly affected by the condition and the setting of the brushes. To such an extent is this true that it is difficult to obtain two consecutive curves which coincide. The slight wearing of the brushes during a run of less than an hour when they are outside the non-sparking region, will introduce changes that entirely mask the variables which it is sought to examine. In fact, the condition of the brushes seems to have more effect on the pulsations than anything else, so that the suggestion has arisen that operators could readily check the setting of the brushes by introducing a coil and electro-dynamometer into the circuit of each machine at such intervals as might be desirable.

TABLE V.

Effects of Field Excitation And Armature Current Upon Fluctuations Through Air Core Transformer. Edison Dynamo on Non-Inductive Load.

Position of Brushes.	Shunt Machine.		Compound Machine.	
	6.4 Amperes.	12.8 Amperes.	12.8 Amperes.	6.4 Amperes
4	267	?	377	203
4½	152	348	193	93
5	59	203	257	105
5½	87	264	100	25
6	30	85	53	20
6½	28	97	79	19
7	26	94	88	17
7½	56	89	24	10
8	56	192	88	49
8½	130	257	57	28

To show how largely the fluctuations of current are affected by the setting of the brushes and the brush yoke, Table V. is given for comparison with Table IV., all the conditions being apparently the same except a small difference in the current. The readings in Table IV. were obtained by going through the whole curve for different positions of brush yoke with one arrangement of the circuits, for example, as a simple shunt machine giving 6.3 amperes, and then changing the circuits and taking readings for another series of brush yoke settings. The readings for Table V. were taken by keeping the brushes and yoke in a constant position, while the corresponding readings for the four curves were obtained with the help of switches that changed the circuits and currents. From an inspection of the two tables it is seen that the same general relations exist among the four corresponding curves, although corresponding curves for the same arrangements of circuit on the two different days do not at all coincide. Some irregularities from undiscovered sources affected the readings so that they are not of best value, yet they illustrate the point that apparently small matters may greatly affect the relative amount of fluctuation in the current.

It was planned to carry on next, a series of experiments to determine the relative pulsations in the currents supplied from a number of individual machines, and a current of equal strength supplied from the same machines working in parallel, but a mishap in the laboratory delayed such work until too late for report at this meeting. It is believed, however, that when a number of machines are operating in parallel, the fluctuations from the various machines combine so as to form a resultant fluctuation less than that from any one machine. This is believed to be one of the two principal reasons why the fluctuations in the current from the rotaries now used by the lighting and railway companies referred to above, are much greater than they were when each company was using a comparatively large number of small machines in parallel.

The other principal reason for the greater pulsation is believed to be the fact that the rotaries now used have toothed armatures and laminated pole-pieces, while the machines formerly used had solid cast-iron pole-pieces and had smooth body armatures. In the case of the rotaries the magnetic circuit has less reluctance and the self-induction of the coils is greater, and the current in the short-circuited coil therefore reacts more strongly upon the field, which responds more readily and so causes the total voltage to vary to a greater extent than occurs with the smooth body machine. It is desirable to test two machines which are identical except that one has a toothed armature while the other has a smooth core armature.

With so many elements liable to change, it seemed at first impossible to obtain the instantaneous values of the current so as to plot curves for the pulsations. The whole pulsation is so small a part of the total, one per cent. or less, that the common methods of getting the curves by fall of potential seemed unpromising, since the voltage on the power fluctuated circuit through quite a range. It was suggested that the pulsations of voltage might be measured directly by putting a battery in the condenser circuit so as to oppose the principal E. M. F. of the circuit, leaving the condenser to be charged only by the pulsating difference between the E. M. F. of the battery and that of the line. Time did not permit trying this method. Another method contemplated was to use two standard condensers, one of which should be connected into the circuit at a fixed instantaneous point, while the other should be connected into the circuit at different points. Thus one would be charged with the whole voltage at one part of the fluctuation while the other would be charged at some definite interval from the first. By connecting the two condensers through a ballistic galvanometer, a kick would be caused by the difference between the two charges. Upon obtaining two standard mica condensers from two different well-known firms, the two were found not to agree within two per cent., and so that method was temporarily laid aside. By the two condenser method, the curve could be obtained in a way similar to a common method for obtaining curves of potential around a commutator, either by the single or double brush method. For this purpose, ordinary paraffin condensers are of little use, since with a water jet device the actual time of contact is a small fraction of a second, even though the condenser be kept charging for a whole minute for each reading.

A number of attempts were made to obtain curves of the instantaneous values of the pulsations of the current, but none gave entirely satisfactory results. A number of curves were obtained, each of which showed a high sharp peak at the point where a commutator bar left the brush. There is in each case another but less marked peak at a point corresponding to the middle of each bar. The exact cause of the second peak has not yet been definitely located, it being probably due either to the entering of a bar under the brush, or to the delayed effect of the fluctuation in the field current.

As stated at the outset, these experiments are only preliminary and incomplete, but they suggest an intensely interesting field for further experiment.

A Paper presented at the 15th General Meeting of the American Institute of Electrical Engineers, Omaha, June 30th, 1898. Secretary Pope in the Chair.

AIR-GAP AND CORE DISTRIBUTION.

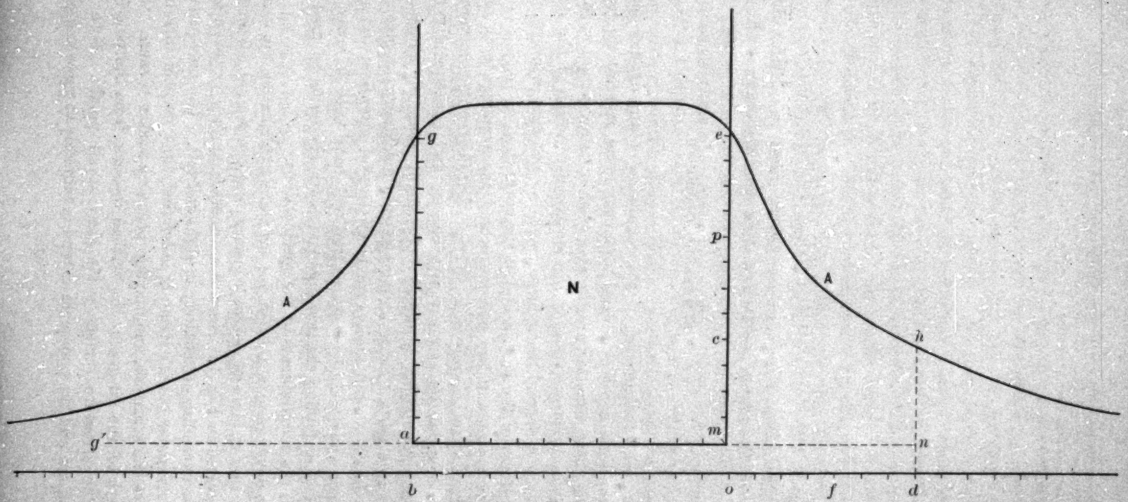
THE MAGNETIC FLUX AND ITS EFFECT UPON THE REGULATION AND EFFICIENCY OF DYNAMO-ELECTRIC MACHINERY.—I.

BY W. ELWELL GOLDSBOROUGH.

The predetermination of the regulation of any dynamo electric machine involves several important steps, and not the least among these, especially in the case of alternating current apparatus, is the determination of the air-gap distribution of the flux, for upon it depend the inductance of the armature winding, the wave form of the E. M. F. and of the current.

The contours of the pole-pieces and the armature teeth of a machine affect, therefore, to an important degree its commercial usefulness, as the air-gap distribution, and consequently the dynamo regulation, is directly dependent upon the shapes of these iron parts. In designing electrical machinery the mechanical details should always be given careful attention, and frequently a method of successive trial will have to be followed to the end of finding the best pole and tooth shapes to be used to fulfil the requirements of the specifications.

In developing a method for accurately calculating the *armature surface* density, let us consider first the simple conditions illustrated in Fig. 1. Here the armature surface is taken as a plane extending indefinitely to right and left. The pole-piece is a rectangular block extending indefinitely in a vertical direction above the armature, and having perfectly square corners. The length of the air-gap or the vertical distance from the pole-face to the armature surface is the same at all points. Both the armature and the pole-piece extend indefinitely at right angles to


g
e
p
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A
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FIG. 1.

the plane of the paper, and Fig. 1 is only a cross-sectional view of the apparatus assumed.

Suppose, now, that a M. M. F. is applied to the pole-piece to set up a magnetic field in the air-gap. Since the permeance of the pole-piece and of the armature is high, we can consider, for all practical purposes, that all points on the sides and face of the pole-piece are at the same potential relatively to the armature surface, and that all points on the armature surface are at the same potential relatively to the pole-piece, and that, therefore, a constant difference of magnetic potential exists between points on the pole-piece and points on the armature. That is, for all practical purposes, there is the same difference of potential between (*a–b*) as there is between (*c–d*) or (*e–f*).

And, *the number of lines of force that pass between any pair of points on the pole-piece and the armature respectively* (as *c–d*, in the plane of the paper) *will be inversely proportional to the distance*[1] *between them. And the strength of the magnetic field at the surface of the armature at any point* (as *d*) *will be proportional to the sum of the reciprocals of the distances of the point* (*d*) *from all the points on the perimeter of the pole-piece made by a section-plane passing through the point* (*d*), as in Fig. 1.

That these assumptions represent a close approximation to the conditions actually existing in dynamo machinery, will be evident when it is remembered that in any dynamo from 60 to 90 per cent. of the M. M. F. impressed upon the magnetic circuit is expended in forcing the flux across the air-gaps, in spite of the fact that these air-gaps are seldom as much as one per cent. of the length of the path traversed by each useful line of force. The drop in M. M. F. is therefore from 600 to 2000 times as great per unit of length in an air-gap proper as it is in an iron portion of the circuit.

The curve A in Fig. 1 represents the distribution of the magnetic flux at the *surface of the armature* as determined by the foregoing method; for the length of any ordinate (*h–d*) at any point (*h*) on this curve is equal to the sum of the reciprocals of the distances of the foot of the ordinate (*d*) from all points (*g* to *e*) indicated on the pole-piece. The curve A extends indefinitely to right and left, and is asymptotic to the surface of the armature. The curve indicates that the strength of the magnetic field does not diminish as rapidly as is usually supposed after the limits of the working air-gap proper are passed.

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[1] In measuring these distances it must be remembered that the most direct path *in air* must be taken, as (*d–a–g*) Fig. 1, *not* (*d–g*) direct.

Fig. 1 illustrates the field strength at the surface of the armature when but one pole is acting upon it. Suppose we bring up another pole, similar in every respect to the first, except that it is of opposite polarity. It will tend to set up the field density at the surface of the armature that is represented by curve B of Fig. 2; but since this magnetic field is opposed to that of the pole N, a field will result that is equal to the difference of the superimposed fields, or to the field strength represented by the curve C, Fig. 2. As a result of the substraction, the flux density is shown to be zero at any point on the surface of the armature that is midway between the two poles, and that the sign of the field is reversed at such point. In this case the strength of the field *at the surface of the armature* is greatest at the center of the poles and diminishes to right and left. The reduction in the strength of the field under the pole corners is marked, and the form of the fringing field is clearly outlined. It is to be further remarked that the contour of the curve C of flux distribution changes its form as the distance between the poles N and S is varied.

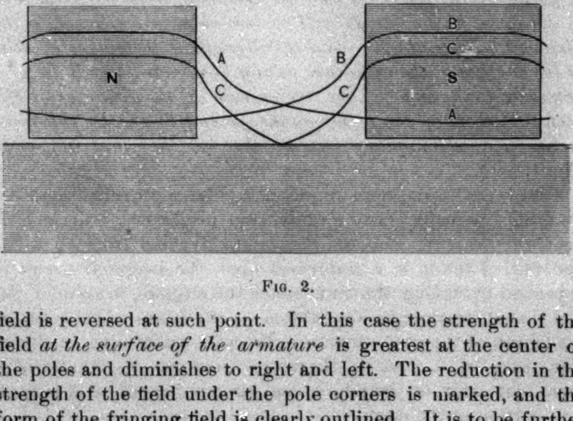

Fig. 2.

The calculation of distribution curves similar to curve A of Fig. 1 is most readily effected by an application of the calculus, although in cases where the contours of either the armature or pole-piece surfaces are very irregular, it may be necessary to space off the pole-piece perimeter and obtain the summation of reciprocals for any given point on the armature by first calculating each one separately.

A simple and most handy formula for use in this connection is that for the determination of the summation of the reciprocals of lines drawn to a series of points on a plane surface. Referring to Fig. 1, let y_e denote the value of the reciprocal $(d–e)$ and c_o the value of the distance $(d–o)$ and x_e that of the distance $(o–e)$,—then,—

$$y_e = \frac{1}{\sqrt{c_o^2 + x_e^2}}$$

Therefore if y denotes the reciprocal of the distance of any point on the surface (g, a, m, e) from d; x, the distance of any point on the line $(o–e)$ from o; z, the distance of any point on the line $(n–g')$ from n; and c_n the distance $(d–n)$, then,—

$$\sum_{x_m}^{x_e} y = \int_{x_m}^{x_e} \frac{d\,x}{\sqrt{c_o^2 + x^2}} = \log\left(x + \sqrt{c_o^2 + x^2}\right) \Big[_{x_m}^{x_e}$$

and, since, as $(a–g') = (a–g)$, the reciprocal of the distance $(d–g')$ approximates the value of the reciprocal of the distance $(d–a–g)$, then,—

$$\sum_{z_m}^{z_g} y = \int_{z_m}^{z_g} \frac{d\,z}{\sqrt{c_n^2 + z}} = \log\left(z + \sqrt{c_m^2 + z^2}\right) \Big[_{z_m}^{z_g}$$

and the value of the ordinate from the point h, or

$$(d - h) = \sum_{x_m}^{x_e} y + \sum_{z_m}^{z_g} y.$$

In estimating the value of the theoretical case that has just been discussed as an aid in the practical design of electrical machinery, it may be well to bring out the points of difference between the assumed and the actual conditions. In the first place the dimensions of the pole-pieces are limited vertically and laterally as well as transversely, and therefore although the assumed condition of field strength distribution may exist in a plane passing through the center line of the side faces of the poles, it does not follow that these conditions will in any wise obtain at the outside edges of the poles. Then again the difference of potential maintained between the armature surface and the poles is not constant for all points on the polar surfaces. It is only constant for points below the magnet windings, while the difference of M. M. F.

between points on the yoke (and at the top of the magnet windings) and those on the armature is zero. In passing through the winding spools therefore the M. M. F. diminishes from a maximum to zero.

As will be shown later, the limitation of the dimensions of the poles in practice does not seem to materially affect the results when the outer ends of the armature coils do not cut the lines of force of the outside or end fringe of the field, and where they do, the strength of this fringe can be determined by applying the construction to the end surfaces.

The matter of the variation in the M. M. F. is not in general of great consequence owing to the fact that the distance reciprocals of points on the poles that are near the yokes are very small as compared with those of points on the working air-gap. It is ordinarily sufficient, therefore, to consider the potential constant to points *half way up to the field winding*, and to carry the summation only to these points. With this thought in mind the summation of reciprocals was only carried to *e* and *g* in determining the form of curve A of Fig. 1. In special cases where on account of modifications peculiar to the design it is deemed wise to take account of the variations in the M. M. F., it is only necessary to multiply each reciprocal by a number that is proportional to the M. M. F. acting on the path from which it is determined. In the application of the calculus to this case a special integration is necessary for the polar points lying within the winding spools.

In bringing forward experimental results to show in how far the method that has been discussed can be relied upon, I will first call your attention to the data that is given by Dr. S. P. Thompson in the second lecture of his "Electromagnet," which refer to the determination of "the relation of leakage to pull" in the case of a horse-shoe electromagnet. He says:—

> "The amount of magnetism that gets into the armature does not go by a law of inverse squares, I can assure you, but by quite other laws. It goes by laws which can only be expressed as particular cases of the law of the magnetic circuit. The most important element of the calculations, indeed, in many cases is the amount of percentage of leakage that must be allowed for."

Dr. Thompson then gives the record of the number of lines of force entering the armature when the latter is placed at successive distances from the pole-pieces.

These give ratios of length of air-gap to width of pole-face of

1/13, 2/13, 5/13 and 10/13, and for this series of air-gaps, sets of readings were taken with exciting currents of .7, 1.7, 3.7 and 5.7 amperes. I have taken the data and multiplied each series by a constant which reduces the short air-gap reading of each to the same numerical value, and have plotted these results in Fig. 3; each series is marked and its points connected by a black line. The initial or short air-gap density of the first series is only .2 of the initial density of the last series, and yet the curves practically coincide, showing that for any given position of the armature relative to the poles, the strength of the field is directly

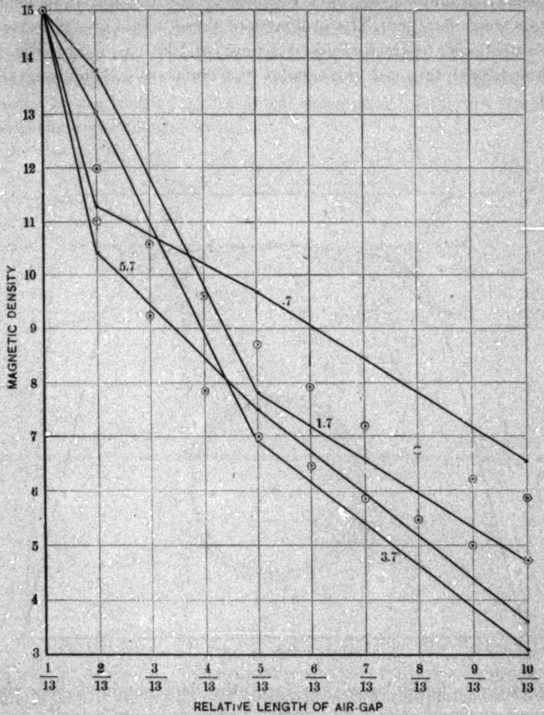

FIG. 3.

proportional to the impressed M. M. F. and that the field distribution of the flux remains constant, as theory requires.

Now supposing the armature of this electromagnet to be a plane surface, and calculating the relative amount of flux that will enter the armature for the several air-gaps, by the method already developed, the data represented by the upper curve of dots were obtained. The ordinates of these points are, therefore, proportional to areas enclosed by curves like curve c of Fig. 2, determined for each position of the armature. Supposing the armature to be of horse-shoe form, the data obtained gave the lower curve of dots. The result for the armature actually used would fall between these two curves of dots. We have here evidence to show that a careful application of this method of *reciprocal summation* will give results within the bounds of experimental accuracy.

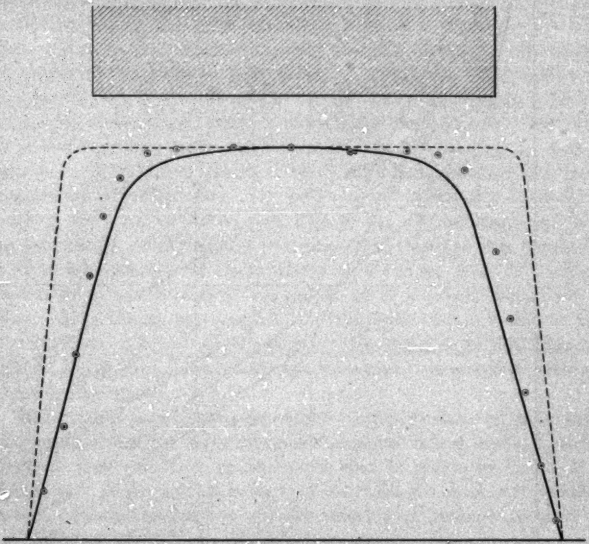

Fig. 4.

An extended series of experiments carried on by Messrs. J. L. Roe and S. R. Fox, under my direction, upon alternating and direct current electromagnets confirm the above.

I am further much pleased that the opportunity is afforded me of calling your attention, at this time, to a set of especially clear and instructive curves recently published[2] from the University of Nebraska. In Fig. 4 I have reproduced in the small circles the graphical presentation of the data from which one of these was plotted. The small circles represent the experimental exploration of the flux distribution in the air-gap of an Edison bipolar dynamo. The curve shown by the black line in Fig. 4 is the calculated curve of flux distribution for this machine obtained by the method of reciprocal summation. It agrees closely with the experimental work.

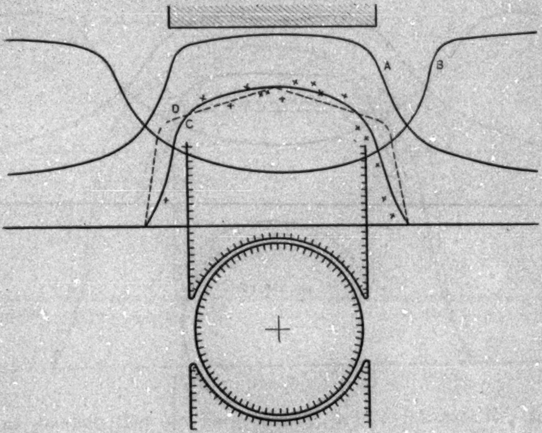

FIG. 5.

The dotted curve of Fig. 4 outlines the flux distribution that is usually *assumed.* Its ordinates are inversely proportional to the length of the air-gap of the dynamo, and it departs noticeably from the real and calculated values through that important space represented by the fringing field.

To give you further evidence of the probable accuracy of results calculated on this basis I have applied the method to the determination of the flux distribution in the air-gap of a 50-K. W. bipolar Jenney dynamo. The design of this machine is such as to admit of a considerable range of adjustment in the mean length of the air-gap. Under normal working conditions the double air-gap of this machine, which has a smooth core armature, is 1.25″ at the center of the pole-faces, and 1.52″ under the leading and trailing pole-tips. The diagram of Fig. 5 presents the conditions existing with this arrangement. Subtracting curve B from curve A, curve C is obtained, and represents the calculated distribution of the flux in the air-gap. The dotted curve D is plotted by taking the reciprocal of the length of the air-gap at successive points, and plotting the results so obtained above corresponding air-gap positions on the diagram. The ordinates of the curve D are therefore proportional to the armature surface density in the air-gap, if this density is taken as inversely proportional to the length of the air-gap. The star-points on the diagram represent the results obtained by exploring the air-gap field by the "pilot-brush" method. As the star-points follow the curve

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[2] "Armature Reactions in a Continuous Current Dynamo," by C. A. Bessey, *The Electrical Engineer*, vol. xxv., p. 511, May 12, 1898.

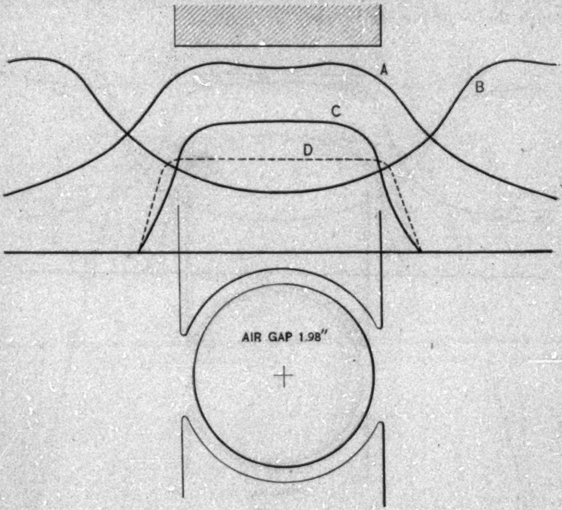

FIG. 6.

C much more nearly than they do the curve D, it seems probable that the calculated values are reasonably accurate.

In Fig. 6 is illustrated the result of imposing another set of conditions upon the same machine. The curve C represents the calculated distribution of the flux in the air-gap when the length of the double air-gap has a constant length equal to 1.98″ at all points. The dotted curve D shows what the relative value of the flux density would be if the strength of the air-gap field were inversely proportional to the length of the air-gap. Since the ordinates of the C curves and the D curves of Figs. 5 and 6 are respectively proportional to the quantities they represent and to one another, they can be compared, and to facilitate this are plotted together in Fig. 7. It is noticeable that the C curve of Fig. 6 represents relatively a very much stronger field than does the D curve. In fact the ratio of the mean ordinates of the C curves of Figs. 5 and 6 is .899, whereas the ratio of the mean ordinates of the D curves is only .699. We see therefore that the rate at which the strength of the air-gap field decreases as the length of the air-gap is increased, falls far short of being inversely proportional to the rate of increase in the mean length of the air-gap, supposing that the C curves represent the true condition.

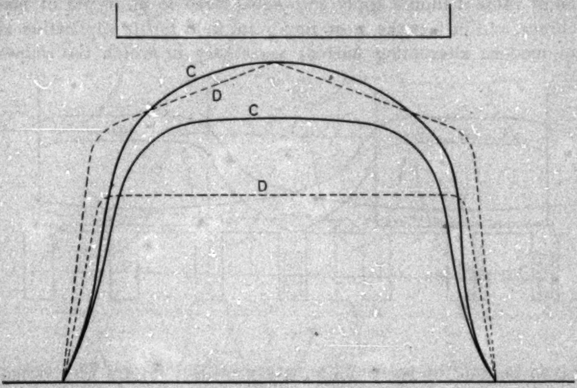

FIG. 7.

This fact is also brought out by the curves of Fig. 3, which indicate that the length of the air-gap had to be increased five-fold before the strength of the field was reduced one-half.

To determine how nearly the calculated results agree with the actual conditions existing in the case of the Jenney dynamo, the magnetic characteristics of the machine were determined both for the short and the long air-gap adjustments; and the ratios of ordinates corresponding to like field currents along the "straight" parts of these curves below the "knee" were found to vary between .824 and .864, the average being about .835. Although not conclusive, these ratios tend to substantiate the calculated results.

Up to the present the application of the method to machines having smooth core armatures has only been considered. But to be of value it should apply with equal force to all types of machines, and in fact the most important field for its application is to modern alternating current machinery in which the shapes given to both the polar and armature projections are very varied in character.

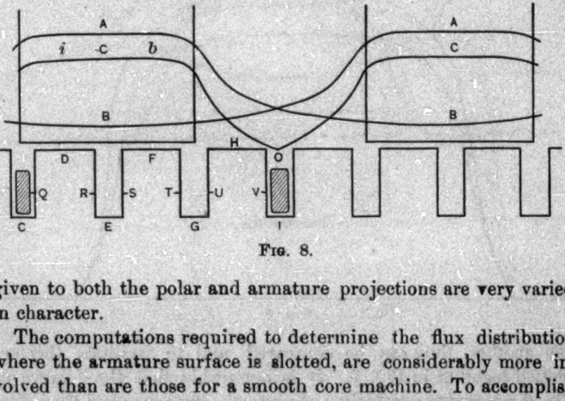

Fig. 8.

The computations required to determine the flux distribution where the armature surface is slotted, are considerably more involved than are those for a smooth core machine. To accomplish a result that will be of value in determining the wave forms of the E. M. F. and of the inductance developed in the armature coils, the armature must be placed in a series of positions, each of which presents a different space position of the teeth to the poles. The complete armature surface distribution of the flux must then be determined for each position of the armature relative to the poles, the exact perimeter of the armature teeth being followed in each case and the measurements being taken from working drawings of the machine. When this has been accomplished a sufficient amount of information will have been obtained to admit of the accurate determination of the rate of change of the flux through any coil on the armature, and consequently of the wave form of the E. M. F. developed in the coil as rotation takes place. In other words, the data will be sufficient to determine the *no load* E. M. F. waves developed in the armature, provided the hysteretic[3] and eddy current disturbances in the armature iron are not sufficiently great to cause a lateral displacement of the wave.

In Fig. 8 is shown diagrammatically a section through the poles and armature of an 8–50–900–1150 two-phase General Electric alternator, the results of calculations in connection with which I wish to report to you at this time. Each of the coils on the armature of this machine embraces three teeth as indicated by the single coil shown in Fig. 8 and in the discussion which follows, I will endeavor to show with what success the wave of E. M. F. developed in these coils has been calculated.

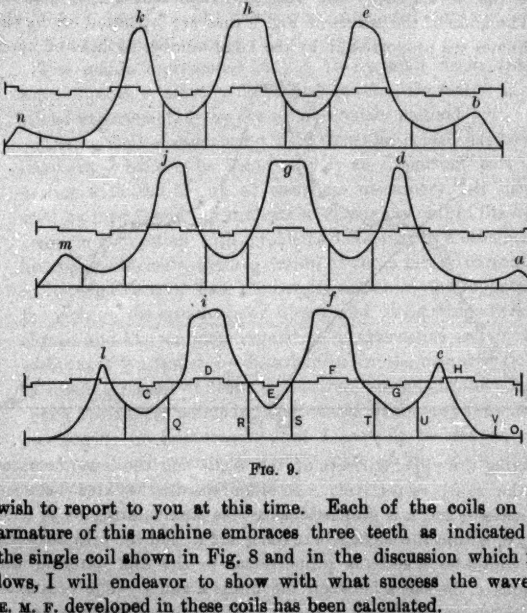

FIG. 9.

The curve o of Fig. 8 represents what the flux distribution in the air-gap would be if the armature core were smooth. Its ordinates are therefore proportional to magnetic density at the upper surface of the teeth. The number of lines of force entering the sides and bottoms of the slots had also to be determined by the method of reciprocal summation. The result of some of this work is shown in Fig. 9, where three of the air-gap distribution curves are plotted relatively to the perimeter of the armature developed into a straight line. The positions of the top of the teeth and the bottoms of the slots are indicated by the breaks in the line through the center of each curve. The curves are determined for positions of the teeth differing by one-third of the pitch of the teeth, and the gradual change in the distribution and amount of the flux that enters a tooth as it passes across the pole-face can be traced by following the small letters *a*, *b*, *c*, *d*, etc.

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[3] Armature Inductance, TRANSACTIONS, vol. xiv., p. 292.

The areas of the curves of Fig. 9 that are separated off by the ordinates are proportional to the total number of lines of force entering the upper surfaces of the teeth and the lower surfaces of the slots, respectively. In other words, the area between ordinates Q and R is proportional to the flux entering tooth D of Fig. 8, within the surface between Q and R; and the area between the ordinates R and S is proportional to the flux entering the bottom of the slot E between the limits R and S. The ordinates to the curves are drawn at points that are opposite the center of coils in the slots and represent the limit of the useful flux entering the coil in the slot considered. The coil shown in Fig. 8 rests in slots C and I, and therefore when the coil is in this position the total area between the ordinates Q and V of Fig. 9 must be taken to be proportional to the total flux entering the coil when it is in this position.

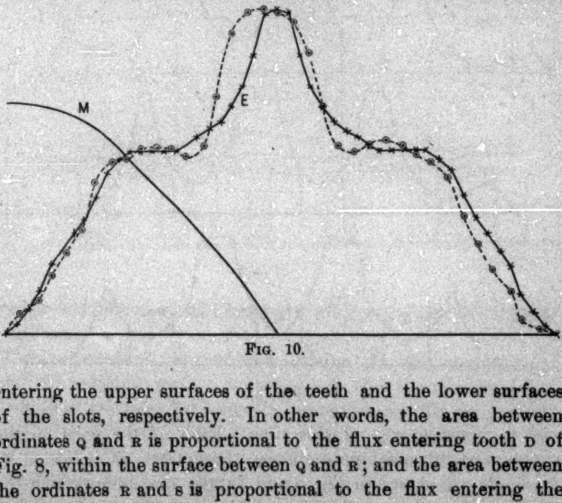

FIG. 10.

In Fig. 10 is shown the curve M, which is the magnetization curve of the armature coils at no load, *i. e.*, its ordinates are proportional to the instantaneous values of the magnetism within the coils as they pass before the poles. The values of the ordinates of this curve were obtained from the distribution curves shown in part in Fig. 9, as already explained.

Now since the rate of change in the amount of flux within the coils is proportional to the E. M. F. developed in the coils, the wave of E. M. F. has been determined directly from the curve M by the method of tangents, and is shown by the broken line and stars of the curve E. The curve E, which is quite an irregular curve, is therefore and finally, the calculated curve of electromotive force developed by this alternator.

The points represented in Fig. 10 by small circles trace the wave of E. M. F. actually developed by this alternator as determined experimentally by the rotary contact method.

The method of calculating field densities which has been outlined can, I believe, be made to play an important part in connection with the design of electrical machinery. It has been used by myself and my students with success within the last two years, in connection with problems involving the calculation of leakage coefficients, the regulation of large direct current units under conditions of load, the determination of the inductance of the coils on the armatures of direct and alternating current machines, and the complete regulation of alternators and motors in so far as it is affected by disturbances in the magnetic field due to rotating masses of iron or reactive currents in the coils. To touch upon these points in detail would make my present paper too lengthy for this occasion, but I hope to be able, at a future meeting, to call your attention to some of the more important problems that have been treated.

Purdue University, Lafayette, Ind., June, 1898.

(COMMUNICATED BY THE AUTHOR AFTER ADJOURNMENT.)

The importance has been emphasized of making due allowance for the fact that the M. M. F. between a point (d, Fig. 1) on the armature surface and a point on the polar surface (between c and e) within the field coil spools rapidly diminishes as the latter point is taken nearer and nearer the yoke, it may be well to add the formula that applies especially to the reciprocal summation of the points within the field coils.

If the M. M. F. impressed upon the magnetic circuit of Fig. 1, were produced by an energized coil occupying the space between the points c and e, the potential between polar surface points below c and points on the armature surface would be uniform and equal to the maximum magnetizing power of the coil. The potential between points above e and points on the armature would be zero, and the potential of points between c and e and the armature would gradually diminish from the maximum value to zero as the points were taken more and more remote from c. Under these conditions, the effect of the reciprocal of $(m - d)$ or $(c - d)$ at d is proportional to its full value; the effect, however, of the reciprocal of $(p - d)$ at d is only proportional to half its full value, while the effect of the reciprocal of $(e - d)$ is zero.

Therefore, the effect of the surface $(c - m)$ at the point d is proportional to

$$\sum_{x_m}^{x_c} y = \int_{x_m}^{x} \frac{d\,x}{\sqrt{c_0^2 + x^2}} = \log\left(x + \sqrt{c_0 + x^2}\right) \Big[_{x_m}^{x_c}$$

while the effect of the surface $(c - e)$ at d is proportional to

$$\sum_{x_c}^{x_e} y = \int_{x_c}^{x_e} \frac{x_e - x}{x_e - x_c} \cdot \frac{d\,x}{\sqrt{c_0 + x^2}}$$

$$= \frac{1}{x_e - x_c}\left[x_e \log\left(x + \sqrt{c_0 + x^2}\right) - \sqrt{c_0 + x^2}\right]\Big[_{x_c}^{x_e}$$

where x_c denotes the distance $(o - c)$ and x_e the distance $(o - e)$. And the total effect of the surface $(m - e)$ at d is proportional to—

$$\sum_{x_m}^{x_c} y + \sum_{x_c}^{x_e} y$$

evaluated as above.

GALILEO FERRARIS.

A Memorial.

The *Associazione Elettrotecnica Italiana* of Milan, Italy, has undertaken the accumulation of a fund for the purpose of erecting a suitable monument in memory of the late Professor Galileo Ferraris. In order to enable his many American friends to participate in this worthy object, which will assume the form of an international tribute, the Executive Committee has authorized the Secretary to receive any contributions that may be made, and which will be forwarded to the Italian Society, through the agency of the American Institute of Electrical Engineers. Remittances by check or money order will be duly acknowledged, and should be made payable to the undersigned.

RALPH W. POPE,
Secretary.

New York, June 24th, 1898.

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